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Acrylic Plastics in Lighting*

By W. E. HARPER, B.Sc.(Eng.),Ph.D.,A.M.I.E.E. *(Member)*,† and
H. P. WALKER *(Member)*†

Synopsis

Acrylic plastics are among the most important of the new materials being used by lighting engineers in the construction of fittings.

Available in many varieties, their optical, thermal, and mechanical properties are reviewed and related to the use of the material in lighting equipment.

Fabrication methods for moulding and shaping the material must be adapted to its characteristics, and details are given of the more widely used techniques, including shaping, high pressure moulding, machining, and jointing.

The developing use of the material in selected fields of lighting practice is outlined, and fittings typical of modern practice described.

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(1) RANGE OF MATERIALS.
(2) PHYSICAL AND MECHANICAL PROPERTIES:—
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Introduction

Co-operation between illuminating engineers and other technologists has resulted in the production during recent years of new materials now widely used in many types of lighting equipment.

Among the several plastics familiar to the designer, polymerised methyl methacrylate(1) is one of the most interesting and versatile.‡ An acrylic polymer largely of British development(2), it came into prominence during the recent war through extensive use in aircraft cockpit covers and astral domes. Success in this application was due to such mechanical properties as high shock-resistance and freedom from splintering, combined with exceptional optical clarity and easy manipulation. These properties, allied to its lightness, variety of form and permanence, have suggested many peace-time applications, prominent among which is its use in lighting equipment.(3)

This development is still in an early stage, but it was thought that a review of the material's characteristics and an indication of trends in design would be of interest to lighting engineers. To simplify the text of the paper the material is frequently referred to as "acrylic sheet," although the group of

* Manuscript received February 19, 1948. Presented at a meeting of the Society held at Harrogate on June 17, 1948.

† Imperial Chemical Industries, Ltd., Plastics Division.

‡ Polymerised methyl methacrylate is best known in this country as "Perspex" acrylic sheet, rod, and tube, and "Diakon" moulding powder. The corresponding American products are "Lucite" and "Plexiglas," the latter name applying also to the Continental material.

acrylic plastics includes many polymers other than polymethyl methacrylate; none of these, however, has commercial importance at the present time.

(1) Range of Materials

In the design of fittings, the lighting engineer requires materials having a wide variety of properties. Considering some optical characteristics, he may call for colourless and coloured transparent materials, diffusely transmitting materials of different types, and diffusely, preferentially and specularly, reflecting materials. From the transparent grades he must be able to mould accurate prismatic patterns, the diffusers must be available in various opacities with closely defined transmission, diffusion and absorption characteristics, while reflectors must be non-selective and of high reflection factor. In addition to such optical requirements the designer demands suitable mechanical and thermal properties, ease of fabrication, good service performance under the most arduous conditions, a high order of reproducibility, and low cost.

An advantage which polymethyl methacrylate shares with the inorganic glasses is the variety of forms in which it can be produced to meet some of these demands. The basic form of acrylic sheet is a colourless, transparent polymer, made in thicknesses ranging from 1/24 in. to 2 in., and in area up to 6 ft. x 4 ft., the maximum size varying with the thickness. Where intricate shapes have to be moulded, a plasticised material can be used, but, as addition of plasticiser lowers the softening point, the unplasticised grade is preferred for most lighting fitting applications.

The very high clarity of this material makes it an excellent medium for carrying dyes and pigments, and sheets are available in colours of red, amber, yellow, green, blue and purple. Although the colours are very reproducible they have not been designed tc meet any colour specification, such as those for signal lenses. Diffusing materials can be regarded as covering a "spectrum" ranging from lightly scattering opals to opaque diffuse reflectors, and the technologist must design products with properties falling at convenient intervals in this "spectrum." Four acrylic opals are made at present in this country, having transmission factors of approximately 80 per cent., 52 per cent., 26 per cent., and 8 per cent., and corresponding reflection factors of 16 per cent., 42 per cent., 66 per cent., and 84 per cent. for sheets $\frac{1}{8}$ in. thick. Production difficulties limit the varieties possible, and it is hoped that these four opals, with properties spaced at these intervals, will meet the majority of design requirements for this group of materials. A number of opals in both pastel and deep colours are also made, but they are too dense for use as diffusing media.

Accurate light control by specular reflection demands reflecting surfaces free from irregularities. Acrylic sheet has the quality of finish of polished plate glass, making it a suitable base for deposition of reflecting coatings. Owing to certain properties of the material it is difficult to deposit metal films on its surface by the chemical methods used in the silvering of glass, and deposition is generally effected by the vacuum evaporation of metals[4], of which silver and aluminium are those of greatest interest to the lighting engineer. Shapings are metallised by the same technique.

Transparent figured materials are frequently used by the designer of decorative lighting fittings, and these can be produced in polymethyl methacrylate by casting the monomer in suitably patterned moulds, or by machining clear sheet.

The varieties discussed above comprise the range of acrylic sheet manufactured in this country at the present time, but other optical effects can be obtained by treatment of the standard products. Light surface diffusion, for

Table 1

1. General physical properties	Specific gravity at 20 deg. C.	1.19
	Linear shrinkage on initial heating for 1 hour at 105 deg. C.	2.0 per cent.
	Water absorption of specimen immersed for 7 days at 20 deg. C.	0.5 per cent.
2a. General optical properties of colourless transparent sheet	Refractive index for sodium D line at 20 deg. C.	1.4900
	Relative dispersion $\frac{(^{n}D-1)}{(^{n}F-^{n}C)}$	58.0
2b. Optical properties of acrylic opals	Transmission factors of $\frac{1}{8}$ in. sheet for parallel light from tungsten source incident normally to sheet	Opal 030=80 per cent. ,, 040=52 per cent. ,, 020=26 per cent. ,, 060= 8 per cent.
	Reflection factors (ditto)	Opal 030=16 per cent. ,, 040=42 per cent. ,, 020=66 per cent. ,, 060=84 per cent.
	*Diffusion	Opal 030=0.14 ,, 040=0.90
2c. Optical Properties of $\frac{1}{8}$ in. metallised acrylic sheet (back surfaced)	Specular reflectivity of back silvered sheet	92 per cent.
	Specular reflectivity of back aluminised sheet	85 per cent.
3. Thermal properties	Vicat softening point	105—115 deg. C.
	Maximum safe operating temperature of mouldings	70 deg. C.
	Thermal conductivity	3.5×10^{-4} c.g.s. units
	Coefficient of expansion	90×10^{-6}/deg. C.
	Specific heat	0.35
4. Mechanical properties	Ultimate tensile strength (20 deg. C.)	8,000—10,000 p.s.i.
	Impact strength (B.S. 488)	0.25—0.35 ft. lb.
	Modulus of elasticity in bend (20 deg. C.)	4.5×10^{5} p.s.i.
	Shear strength (20 deg. C.)	8,500—10,000 p.s.i.
5. Electrical properties	Surface resistivity	Greater than 10^{11} ohms.
	Volume resistivity	Greater than 10^{15} ohm./cms.
	Power factor	0.036 at 800 c.p.s. and 20 deg. C.
	Permittivity	2.95 at 800 c.p.s. and 20 deg. C.
	Breakdown Voltage	390 volts./mil. at 75 per cent. R.H.

* An arbitrary value of diffusion is taken as B_{45}/B_0, where B_{45}=brightness of specimen when viewed at angle of 45 deg. and B_0=brightness of specimen when viewed normally, for parallel light incident normally on the reverse side of the specimen. Diffusion of "perfect" diffuser=1.0.

example, can be produced on the transparent material by sandblasting or by solvent treatment, the latter process being the more satisfactory as sandblasted surfaces are easily marked and difficult to clean.

In addition to the sheet material, polymerised methyl methacrylate is also available as cast tube and rod, and as injection moulding powders, and these alternative forms are finding applications in specialised lighting equipment.

(2) Physical and Mechanical Properties

Polymethyl methacrylate is built up from long-chain molecules, the length of these molecular chains governing some of the thermal and mechanical properties of the polymer. By close control of the manufacturing processes, variations resulting from variations in chain-lengths have been minimised and a highly consistent product obtained.

This acrylic plastic has some characteristics fundamentally different from those of other materials with which the fitting designer is more familiar. For example, at temperatures below 70 deg. C. its behaviour is that of a hard, non-crystalline solid, but above 90 deg. C. its character changes, the material becoming increasingly flexible, taking on some properties similar to those possessed by natural rubber at room temperatures.(5) Values for the more important physical and mechanical properties are set out in Table 1, those of greatest importance to the lighting engineer being discussed in the sections which follow.

(2.1.) Optical Properties

Perhaps the most obvious optical property of colourless acrylic sheet is its high clarity, an impression confirmed by the spectral transmission curve (Fig. 1). For thicknesses up to two inches experimentally determined transmission factors approximate to 92.5 per cent., a value approaching closely to that for zero absorption. This property has found interesting application in lighting by total internal reflection, some examples being described in Section 4.

Transmission of near ultra-violet radiation is also high, and with a value of 90 per cent. at 3650A°, the material should be an efficient carrier for luminescent powders activated by radiation of this wavelength.

Due to absence of crystallinity in its structure, unstressed transparent polymethyl methacrylate is optically isotropic, with constants showing negligible variation from batch to batch.

Representative values for transmission, reflection and diffusion factors of

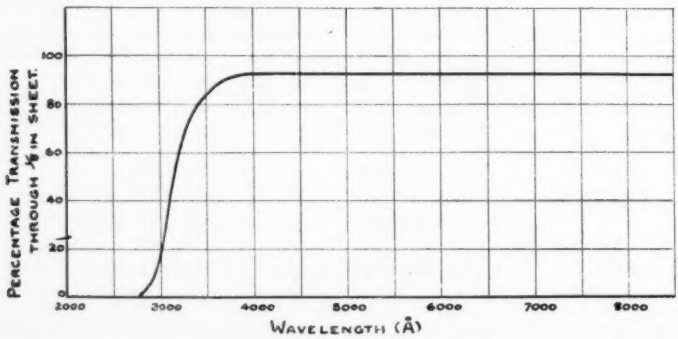


Fig. 1. Spectral transmission curve of ⅛" acrylic sheet: visible and ultra-violet regions.

the four acrylic opals are included in Table 1, and variations from these values do not generally exceed ± 2 per cent. for sheets of the same thickness. In some ways, the most interesting of these materials are grades 030 and 060. With a total reflection factor of 84 per cent., opal 060 is a very efficient diffuse reflector. High surface gloss enables it to be treated in the same way as vitreous enamel when designing contours in relation to the specular component of the reflected flux.

In the same way, it is the high transmission which makes opal 030 particularly interesting. Designed primarily for use with tubular fluorescent lamps, the diffusion of this opal is comparatively low, but its scattering properties in $\frac{1}{8}$-in. thickness are sufficient to obscure the filament of a tungsten lamp for all surround brightnesses. Optically its performance is similar to that of some sandblasted clear materials, but it is without the disadvantages inherent in rough surfaces. Higher diffusion with a transmission approximating to that of flashed opal glass characterise the opal 040, this material in $\frac{1}{8}$-in. sheet also obscuring a lamp filament. The fourth opal, 020, is much used for fluorescent lamp reflectors, the balance between its reflection and transmission factors giving acceptable illumination values on the working plane combined with good ceiling illumination.

When sheets of these acrylic opals are moulded to form lighting fittings, variations in thickness occur, and their effect on the relevant optical properties must be taken into account when assessing probable performance. To

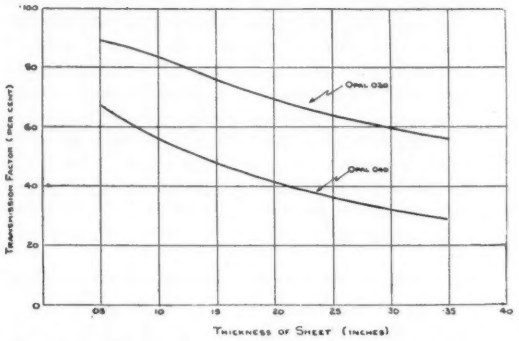


Fig. 2. Relation between transmission factors and thickness of acrylic opal sheets.

assist the designer in making such corrections, experimental curves relating transmission factors of opals 030 and 040 to sheet thickness are given in Fig. 2. Excessive thinning during shaping of opal fittings for use with clear tungsten lamps results in the filament being visible through the material over areas whose thickness is less than a critical minimum value. For a surround brightness of 2 candles per square inch, two sets of critical thicknesses corresponding to two different criteria of filament visibility have been determined for the opals 030 and 040 (Table 2). Usually, the criteria of "apparent visibility" define the minimum thickness, and a combination of initial sheet thickness and moulding technique must be adopted to give component sections greater than this critical value.

The specular reflectivities of the silvered and aluminised sheet call for little

Table 2

Minimum Thickness of Acrylic Opal Sheet for Non-visibility of Tungsten Lamp Filament

Material	Minimum Sheet Thickness when Filament is :	
	(*a*) "Just Visible"	(*b*) "Apparent"
Opal 030	0.095 in.	0.080 in.
Opal 040	0.097 in.	0.090 in.

comment, being typical of values obtained for these metals when deposited on any highly polished transparent surface.

This short survey suggests that the different forms of acrylic sheet can meet many of the optical requirements of the lighting fitting designer, but continued collaboration between illuminating and materials engineers will doubtless lead to the introduction of varieties with new properties.

(2.2.) Thermal Properties

Being a thermoplastic, acrylic sheet can be softened by heat and moulded to shape. On further heating, it demoulds and returns to its original shape. This heating, moulding, and demoulding cycle can be repeated indefinitely. As many lighting fittings operate at temperatures considerably above the ambient temperature, this thermal characteristic will often determine whether polymerised methyl methacrylate is suitable for a particular application or not.

The temperature at which demoulding occurs must not be confused with the softening point of the material, which is a higher temperature. As the temperature rises beyond the softening point, the sheet becomes increasingly flexible until at 180 to 200 deg. C. depolymerisation sets in, being recognised by the formation of small blisters.

The dimensional stability at high temperatures of shaped or moulded acrylic sheet depends on many factors, including the physical properties, the thermal history of the material, and the amount of strain "locked" in the shaped component.

Investigations in progress have been designed to elucidate some of the

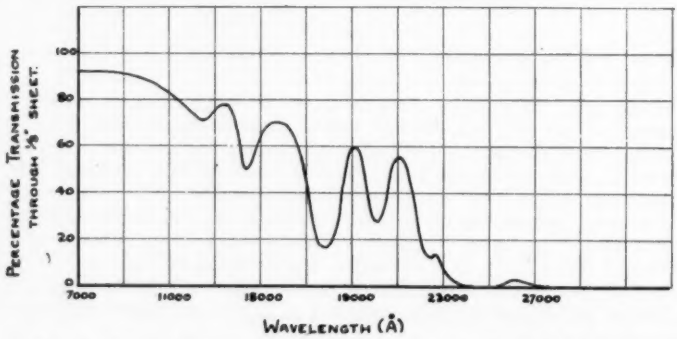


Fig. 3. Spectral transmission curve of ⅛" acrylic sheet: infra-red region.

problems associated with demoulding of acrylic shapings used in lighting fittings, but, until this work is completed, only general guidance can be given to the designer. Allowing a reasonable factor of safety, the operating temperature at any point on the external surface of an acrylic moulding should not exceed 70 deg. C. If type tests suggest that a shaping will operate satisfactorily at higher temperatures, sufficient margin should be allowed to cover variations associated with the material and with the moulding conditions. Due to the low thermal conductivity of polymethyl methacrylate, considerable temperature gradients are set up in the material when the heating is localised, as by narrow convection streams. Such localised heating, associated chiefly with tungsten and H.P.M.V. lamps, may cause local demoulding, and, where possible, the fitting should be designed to break up these streams and distribute the heating over a wider area.

Acrylic sheet has a marked absorption for radiation of wavelengths greater than 14,000 A° (Fig. 3), and this property, combined with low thermal conductivity, causes acrylic components to reach higher temperatures than similar glass components in the same operating conditions.

In this discussion the relatively low demoulding and softening points of the material have been treated as limiting properties, but from the fabrication point of view, they are considerable advantages, and result in easy manipulation.

In some fittings, acrylic mouldings are mated to metal housings, and allowance must be made for the differential expansion of the materials. It is preferable to avoid rigid anchoring of mouldings to supporting metal flanges, but, where this is not possible, as in some forms of flameproof equipment, the mechanical properties of polymethyl methacrylate enable it to distort without fracture. In common with other thermoplastics, the coefficient of expansion varies with the temperature as shown in Fig. 4.

The material is almost immune to damage from thermal shock. After heating to its softening point, it can be plunged into cold water without measurably affecting its physical properties. There is little danger that acrylic components will fracture through the thermal strains set up when rain or cold air draughts impinge on hot fittings.

Polymethyl methacrylate will burn, though its burning rate is low and it is difficult to ignite except by an open flame playing on an exposed edge.

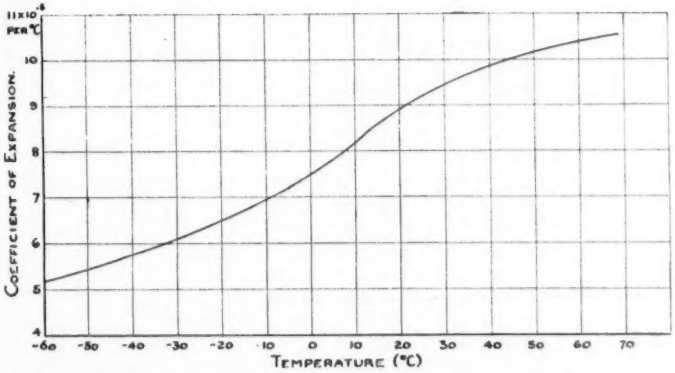


Fig. 4. Relation between coefficient of expansion and temperature of acrylic sheet.

Ignition by such short duration arcing as may take place in a lighting fitting before the fuse melts is very improbable.

(2.3.) Mechanical Properties

The mechanical properties of any material used for the optical components of lighting fittings interest the designer in at least two ways. He is concerned with general strength requirements associated with the operation of fittings in ordinary locations, and also with requirements defined by specification for fittings used in special locations, such as mines. Polymethyl methacrylate combines a low specific gravity with reasonably high tensile and impact strengths, and consequently gives shapings light in weight, self-supporting, and sufficiently strong to withstand normal handling and service operation without breakage. In thin sections, the material can be flexed to an appreciable extent without fracture, a property which can simplify packaging, and reduce the risk of damage during production and transport.

The mechanical properties of many materials depend upon their history, including, for example, the method of production, thermal treatments to which they have been subjected, and strains induced in them by mechanical working. The values listed in Table 1 refer to acrylic sheet as cast. When the sheet is deformed in moulding, the chain-like molecules, initially distributed at random, are oriented to a greater or lesser degree, and this structural change modifies the value of some of the properties, increasing both the modulus of elasticity and the ultimate tensile strength, but decreasing the impact strength. Allowance must be made for this effect when estimating the probable strength of mouldings.

One consequence of the rubber-like nature of polymethyl methacrylate is a marked change in mechanical properties with temperature over a comparatively small temperature range. When discussing this characteristic earlier in the paper, it was suggested that the material could be regarded as a solid below 70 deg. C. and as a rubber at higher temperatures, and while in general terms this is true, the transition is gradual, as shown in the curves of Fig. 5.

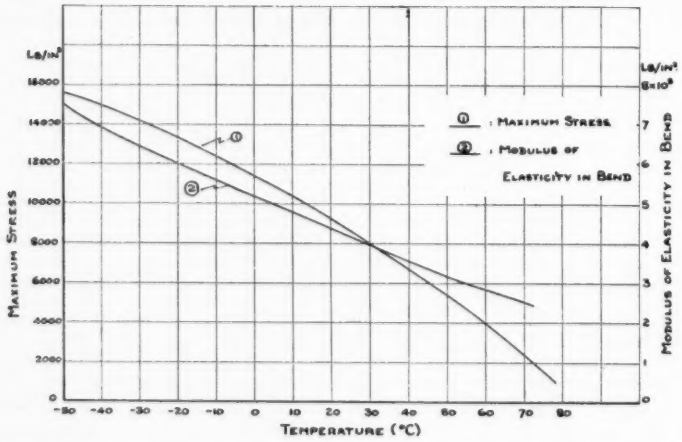
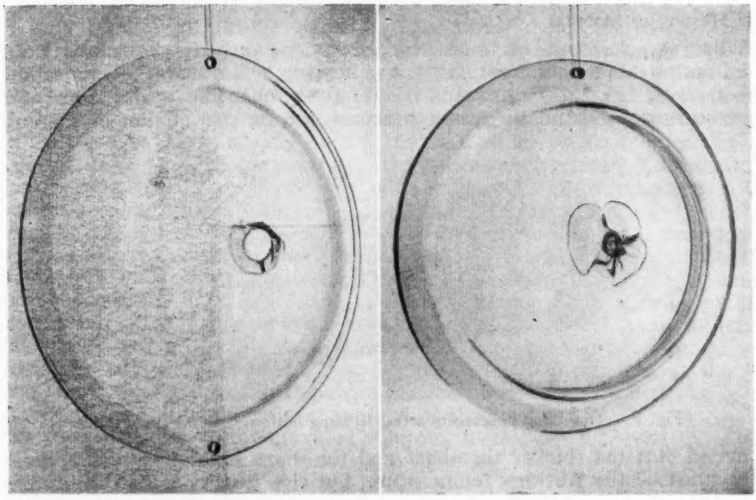


Fig. 5. Relation between mechanical properties and temperature of acrylic sheet.

Unlike some thermoplastics, polymethyl methacrylate is free from embrittlement at low temperatures, the impact strength being almost constant from + 20 deg. C. to − 40 deg. C.

Optical components of flameproof fittings must be sufficiently strong to satisfy the static hydraulic test and impact test clauses of B.S. 889. When acrylic mouldings are used, it is usually the impact strength requirement which determines the minimum thickness of material.

When an acrylic moulding is broken by an impact blow little splintering occurs. The photographs of Figs. 6a and 6b show the fracture areas of two domes subjected to blows of different severity by a round-nosed hammer. The



(a) (b)

Fig. 6. Acrylic domes fractured by impact blow.

dome of Fig. 6a was punctured, but the area of damage is localised. With a less severe blow, the outside surface of the dome remained intact, but flaking from the inner surface occurred, the damage again being limited to the area immediately surrounding the point of impact (Fig. 6b).

(2.4.) Chemical Resistance

The chief interest of the lighting engineer in the chemical resistance of materials concerns their weathering properties, an aspect dealt with in Section 4 of this paper. There are, however, two other characteristics of importance in the use of polymethyl methacrylate. Some thermoplastics have a water absorption so high that their dimensional stability is affected when they operate in atmospheres of high humidity. This limitation does not apply to acrylic mouldings, as the water absorption of the material is too low to affect them dimensionally. Data given in the appendix shows that polymerised methyl methacrylate is unattacked by a wide range of acids and alkalis, but atmospheres containing a high concentration of one of its solvents, such as

acetone, may cause swelling and crazing, a factor affecting the use of the material in some forms of flameproof equipment.

(3) Fabrication Techniques

One of the outstanding advantages of acrylic sheet is the comparative ease with which it can be formed into complex shapes. For many mouldings the equipment needed is simple, and a high rate of output can be combined with adherence to close dimensional tolerances. A number of different shaping techniques are available. The method adopted for moulding is usually related to the design and particularly to variations in sectional thickness, a relation discussed below.

(3.1.) Heating of Material

Whatever forming or moulding operations are to be undertaken, a preliminary process common to all is the heating of the material to a temperature of about 140 deg. C. to bring it into the rubber-like state. The precise temperature depends on the sheet thickness and on the amount of shaping to

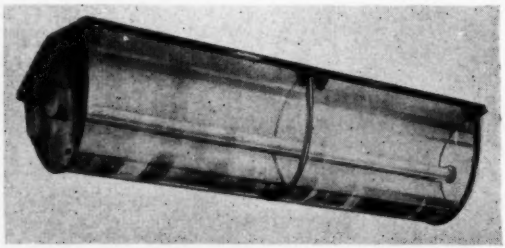


Fig. 7. Two-lamp fluorescent street lighting lantern with acrylic cover.

be carried out; the thicker the sheet and the more involved the shaping, the higher must be the working temperature, but this usually lies in the range of 130 to 150 deg. C. Heating, which must be uniform, may take place either in enclosed ovens or by infra red radiation [6]. Uneven heating causes uneven flow during forming, and results in deformed shapings.

(3.2.) Shaping

Shaping of acrylic sheet consists essentially of stretching or deforming the material while it is in the flexible, rubber-like state, and allowing it to "solidify" through cooling before removing the constraining forces. Moulding and shaping techniques are so numerous that it is only possible to give an outline of some of the more important processes. Perhaps the simplest shaping is the single curvature bend illustrated by the covers of some fluorescent-tube street lighting lanterns (Fig. 7). To produce such a cover, a heated sheet is placed on a contoured wood mould, clamped and allowed to cool in position. If the shaping is removed from the mould too quickly, warping may occur.

When an acrylic moulding has the form of a bowl or dish it can sometimes be made by expanding the heated material into free air using a suitable air pressure, the sheet being clamped at its edges with a retaining ring of the required contour. The hot, flexible sheet is stretched to the hydrostatic shape corresponding to the shape of the retaining ring, and to a depth controlled by the air pressure, which may vary from 5 to 30 lb. per square inch, depending on the size and thickness of sheet. As the material is subjected to pure stretching, its

thickness is reduced to an amount dependent on the final shape and size. This method of forming is economical in material, and, as the sheet does not come into contact with any restraining surfaces, shapings entirely free from blemishes are obtained. In spite of its advantages, the free-blowing technique has obvious limitations, chief of which are restrictions on shape, and more frequently the material is blown into a mould whose surfaces constrain the expanding sheet to the required contour. The mould may be of metal or wood, precautions being taken to minimise mould marks. Metal moulds should be highly polished and wooden moulds protected by soft, stretched glove fabric coated with a pure lubricating grease or with paraffin wax.

Moulding by blowing has a natural corollary in moulding by vacuum suction. The heated sheet is clamped at its edge as before, and sucked downwards into a female mould. In vacuum "snap-back" moulding, the material is clamped by a metal ring over the aperture of a strong box connected to a vacuum chamber. When the vacuum is applied, the hot sheet is drawn downwards into the box forming a large "bubble," into which a contoured male tool is inserted. The tool is clamped in position, and the vacuum released, when the stretched sheet springs back on to the tool, air pressure being applied, if necessary, to force the material into the curves of the tool. This moulding technique produces the most uniform thinning in section for shapes with low re-entrant angles and fairly sharp corners.

Acrylic sheet can also be formed by simple pressing with a male tool, a method used to reduce thinning in deep draws. Trough reflectors for tubular fluorescent lamps are typical of mouldings made by this method. Although moulding pressures are low—of the order of 100 lb. per square inch—metal or phenolic resin laminate tools should be used as wood tools are liable to deform and split over a long period of service. Where deep draws are required with but little thinning, extra material must be drawn into the mould as the tool enters. For this, the edges of the sheet are left loose during the stroke of the tool, and clamped automatically at the end of the stroke.

Very deep draws with controlled thinning have been achieved by a technique in which pressing is combined with blowing.

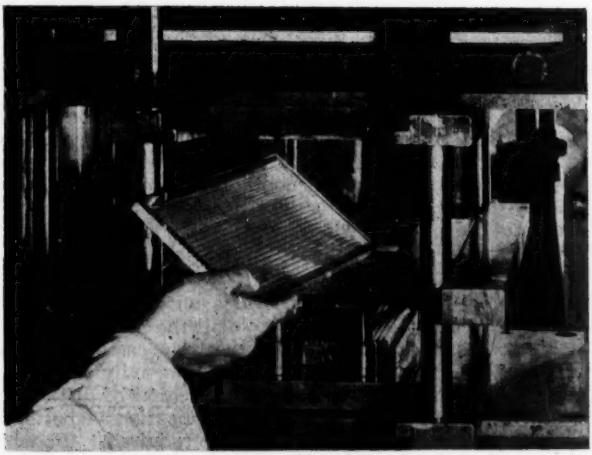


Fig. 8. High-pressure moulding of acrylic sheet. Removing prismatic plate from mould

(3.3.) High Pressure Moulding

Earlier in the paper it was suggested that some forms of the prismatic refractors used so extensively in lighting practice could be produced by moulding acrylic sheet using a suitable technique.

Moulding is carried out at pressures of 1 to 6 tons per square inch in heavy hydraulic presses, using highly polished mild steel tools. (Fig. 8.) Tool wear is very small, so that the initial quality of mouldings is maintained over long production runs.

The acrylic sheet may either be cut to an exact size giving no flash, or a blanking edge can be incorporated in the tool, which should also have vent holes to release trapped air.

The sheet is uniformly heated to 140 to 160 deg. C. and then inserted in the mould, whose top and bottom forces are maintained at 50 to 70 deg. C. to avoid chilling and crazing the material. Pressure is then applied and held on for a sufficient time to prevent distortion of the moulding when it is removed from the press. To decrease the overall time cycle, the moulding can be removed at temperatures of 50 to 60 deg. C and cooled in a separate jig.

Component design must be carefully considered if satisfactory mouldings are to be obtained, and here again it is necessary to remember the essentially rubber-like nature of the material. Polymerised methyl methacrylate does not flow during moulding as does a thermosetting powder; it undergoes a pressure deformation. For the successful moulding of, for example, a refractor plate, the prismatic system of the plate should be so designed that the displacement of material is as uniform as possible over the whole surface.

The method gives mouldings of very high accuracy, as shown by the successful production of directional lenticular screens with a groove pitch of 1/200 in.

(3.4.) Machining

Acrylic sheet machines easily and well to fine tolerances using ordinary woodworking and metal working equipment. Engineers concerned with the production of lighting fittings are mainly interested in methods for cutting, trimming, drilling and finishing the sheet material and shapings. Bandsaws, circular saws or abrasive discs may be used for cutting, the two latter machines giving the best finish for straight cuts. After shapings have been removed from the mould, it is usually necessary to trim and finish them, and frequently to drill or cut fixing holes. Edges can be spindle moulded, but where the production rate is high, it is better to carry out the work on a routing machine, using a template. Both machines have the advantage that they can be operated without lubricant, and give a smooth finish free from chipping. When working polymethyl methacrylate, it is very necessary to clear the swarf from the cutter edge, and the high speeds at which spindle moulders and routers run assist this operation. It is inability to clear the swarf which makes reciprocating saws unsatisfactory for use with this material.

Acrylic sheet can be drilled and turned dry, but a lubricant must be used if the best finish is to be obtained. Ability to drill the material is an important advantage, allowing shapings to be bolted directly to castings or canopies. It is not often that mouldings for lighting fittings are heavily stressed, but, when this does occur, radial cracks may develop in the region of drilled holes unless the walls of the holes are polished. For some applications a better edge finish to shapings than that given by a router may be required. Polishing is best done by a linisher using, firstly, belts of correctly chosen grades of glass cloth,

followed by fabric belts loaded with rouge or buffing soap. Shapings used in lighting by total internal reflection need highly polished edges.

Metallised sheet can be machined in the same way as the ordinary material, but cut edges should afterwards be sealed with a suitable paint to prevent peeling and edge attack.

(3.5.) Jointing and Welding

Generally speaking, the most economical and satisfactory method of producing fittings from acrylic sheet in quantity is to complete the work in the mould, leaving only edge trimming to finish. Sometimes, however, it is necessary for components to be jointed or local areas of a fitting reinforced, and recourse must then be had to cementing or welding. Advantage is taken, for this process, of the solubility of the material in certain organic liquids, the two most useful solvents being chloroform and ethylene dichloride. Liquid solvent jointing is used where the mating surfaces fit accurately and where the solvent is easily applied, but where there is a thin glue line, or where sheets are to be laminated together as in lap joints, a liquid cement is employed. With both methods of jointing, it is advisable to hold the component pieces in a jig until the cemented surfaces have hardened sufficiently to handle. Full strength in the joint, amounting to 50 to 70 per cent. of the strength of the solid material, is not developed for 24 to 48 hours.

Attempts to weld polymethyl methacrylate by more conventional means have had a limited success but are not very suitable for production processes; simple solvent jointing and cementing have proved in experience to be the most satisfactory and versatile processes. It is, however, worth emphasising again that the designer of acrylic shapings should aim at the production of a completed component by a single moulding operation.

Lighting engineers are probably more concerned with the attachment of shapings to metal housings than with the jointing of separate components and some attention is being given to this problem. It has been suggested earlier that important advantages of the material are its ability to support its own weight, its ability to withstand clamping stresses, and its good machining properties, and these advantages can be turned to account when designing methods of fastening. While the material can be tapped quite easily, the resulting threads are not very strong, and it is usually preferable to bolt shapings to their housings, using clearance holes of sufficient size to allow for expansion

It is not always possible, however, to use direct mechanical attachment For example, the covers of mine-lighting fittings must, at present, be cemented into retaining rings using a gap-filling cement of the "Kaffir" type, and such cements have been used with considerable success. This process is, however, unsatisfactory from the production point of view, and alternative systems are being investigated, including the use of gaskets. The flange of the shaping can be machined flat to within close limits, and a gasket cemented to it. By using a special acrylic cement, which is absorbed to some extent by materials such as compressed cork, the gasket is very strongly bonded to the shaping.

(4) Application in Lighting Fittings

The actual applications of acrylic sheet in lighting fittings are extensive and varied; those chosen for description here are either types that have already proved themselves satisfactory in service or are new developments of special interest.

(4.1.) Industrial and Commercial Lighting

This heading includes fittings used in both factories and offices, two applications which have several features in common.

The first acrylic plastic unit to be extensively made was a trough reflector for fluorescent lamps, using the 020 opal sheet. It will be apparent from the figures given that ⅛-in. material of this grade should be a very suitable reflecting medium, as it has a sufficiently high reflection factor to give downward light practically equivalent to that of enamelled reflectors, with sufficient transmission to provide adequate ceiling illumination. The actual balance of downward and upward light depends to some extent on the method of shaping, as the amount of thinning, and consequently the transmission, varies with the method used; further modification of the upward light is made by the top metalwork. In general, however, the downward component comprises about 85 per cent. and the upward component 15 per cent. of the light output of the fitting. This type of unit has advantages when compared with a similar type of trough in enamelled steel, as good ceiling illumination is gained with little loss of downward light, the absorption losses of flat acrylic sheet being only about 8 per cent. compared with 15 to 20 per cent. in most enamels.

Tests of acrylic reflectors over periods of more than three years show exceptionally good maintenance of light output due to the negligible change in reflection factor of the material with time in all atmospheres.

Among the various types of reflector now made, each with its own particular advantages, are:—

(1) Complete troughs as shown in Fig. 9,
(2) Troughs with metal or opaque ends;
(3) Units made with plastic wings attached to the sides of the centre spine;
(4) Single reflectors with open ends attached to a centre spine.

The success of these different types indicates the wide design scope and versatility of this reflecting material.

The dense acrylic opal 060 has not been extensively used in trough reflectors for fluorescent lamps, as the additional upward light given by reflectors made from the 020 material has been preferred to the extra illumination on the working plane which would be obtained by the use of the dense variety.

Both opal materials are now being considered for industrial dispersive-type reflectors, using tungsten lamps. One of the chief difficulties in this application is the high temperature reached in the region of the reflector neck, particularly when the unit is enclosed with a diffusing bottom plate. Encouraging results have, however, been obtained with 14-in. reflectors for 150-watt and 200-watt lamps with both ventilated and enclosed galleries.

To summarise, the advantages offered by the acrylic opals in the types of reflecting units discussed are:—

(1) Resistance to damage by impact and general handling;

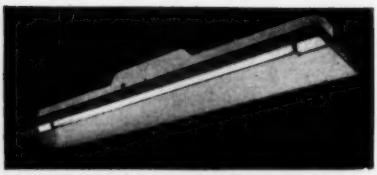


Fig. 9. Single moulding fluorescent lamp reflector.

Fig. 10. Enclosed twin-lamp fitting using machine-fluted acrylic sheet.

(2) Maintenance of light output during life;

(3) Resistance of the reflecting surface to corrosion, including freedom from discoloration;

(4) Low absorption giving a reasonable ceiling illumination with a good illumination on the working plane.

The introduction of the high transmission diffusing opal 030 should help to fulfil the demands of those who require a diffusing medium for use with fluorescent lamps. Its diffusion is sufficient to flash the aperture of a normal diffusely reflecting trough, while its transmission is high enough to prevent a "dead" appearance. This material is likely to replace sandblasted materials, as it does not suffer from "finger-marking," which presents such a serious cleaning difficulty. Its possible use in transmitting troughs is extensive, as shaped sections can be self supporting, enabling carrier metalwork to be largely eliminated.

As a visor for industrial dispersive reflectors, this high transmission diffuser should prove a useful and efficient material, being little subject to damage by either mechanical or thermal shock, easy to clean and easy to fix.

For more decorative commercial units use is made of clear material with some surface diffusing finish. Most popular of these appear to be designs using machine-fluted transparent sheet. Many attractive fittings have been made in this style, a typical example being shown in Fig. 10. To prevent lamp-holders being visible the ends of such units are often sprayed with a white diffusing lacquer. Fluted material of this nature is perhaps less efficient than the high transmission acrylic opal, but is sometimes preferred as the internal reflections give an attractive sparkle when compared with the comparatively plain surface illumination of the diffuser.

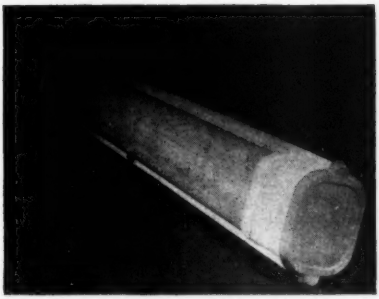


Fig. 11. Corrosion-proof fitting for 80-watt fluorescent lamp.

Decorative effects with white or coloured lacquers can be obtained by spray painting through a stencil, and, if correct lacquers are used, adhesion is good. Generally speaking a lacquer whose solvent attacks the material gives the best adhesion.

(4.2.) Industrial Lighting—Corrosion-Proof Fittings

In many industrial situations damp acid-laden atmospheres cause corrosion of most metals and destroy vitreous and stove enamel finishes through attack on the metal base. Particularly subject to this trouble are fittings used over acid pickling vats and in dye works. In Fig. 11 is shown an acid-proof fitting expressly designed for service in such conditions. It is made in acrylic sheet, the top half being in reflecting opal and the bottom half in clear material. The lamps can be changed from the ends of the fitting, and are supported by transparent acrylic ribs. The ends of the unit are closed by rubber caps and no metal is exposed. Fittings of this type have been in service for a considerable time in a large chemical factory and show no deterioration in atmospheres that ruined normal fittings in a few months.

(4.3.) Street Lighting

The first large-scale application of acrylic sheet in street lighting was in fluorescent lanterns.(7) Here a large transparent area was essential, and, owing to the fitting dimensions, glass was difficult to apply. Certain plastic materials obtainable in thin sheet form, such as ethyl cellulose, were considered, but it was found that they were comparatively bad light transmitters, showed a tendency to yellow with continuous exposure to the atmosphere, and were suspect regarding dimensional stability. Acrylic sheet appeared to meet most of the designers' requirements, and its heat transfer being low, in cold weather it helps to maintain the internal temperature of the fitting at a level which enables the lamps to function with reasonable efficiency. Fittings are made in two-, three- and four-light types, a typical two-light unit being shown in Fig. 8.

A possible new development is the substitution of a blown or pressed bowl for the plain bends now generally used, an alteration which will permit the metal ends to be discarded and give a fitting of less weight. Installations of fluorescent lanterns have now been in service for over two years, and reports indicate that the deterioration of the surface of the material by abrasion is negligible.

The comparatively low operating temperature of sodium vapour lamps

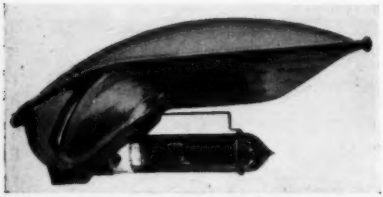


Fig. 12. 45/60-watt sodium street lighting lantern with mirrored acrylic reflector and opal cover.

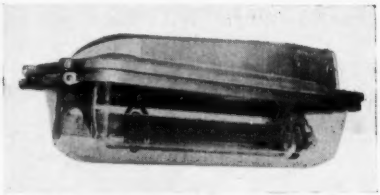


Fig. 13. 140-watt sodium street lighting lantern with enclosing dish moulded from acrylic sheet.

suggests that acrylic materials might be used in various types of fitting. The first experimental unit made was an 85-watt symmetrical mirror fitting of box construction with cemented edges, the mirror surface being hermetically sealed from the atmosphere. The unit has now been on test service for twelve months, and has been cleaned in the same way as the mirrored glass units in the same installation. Results to date show that surface deterioration is negligible.

Following this initial experiment a 45-watt asymmetrical unit was designed (Fig. 12). This unit is interesting as an example of a fitting made almost wholly from acrylic sheet. A shaping for the faceted wing type reflector was formed by blowing ¼-in. sheet into a metal female mould of required contour, the shaping being subsequently metallised. Many experiments were necessary before a satisfactory moulding was obtained, particular difficulty being caused through the formation of unwanted ridges in the material during the shaping operation. The reflector was closed by a slightly domed top cover, vacuum moulded from coloured opal sheet, the reflector and cover being cemented together round their edge flanges. This "optical unit" was bolted to a small tunnel-shaped casting surrounding the lampholder, the whole forming a light and efficient unit.

Requests for a completely enclosed sodium lantern led to consideration of the use of acrylic sheet for the enclosing dish. A design was prepared for

a 140-watt reflector/refractor lantern, in which the dish measured 25 in. × 9½ in. × 6½ in., and had a $\frac{3}{16}$-in. thick ½-in. wide fixing flange. This dish was produced by the "snap back" moulding technique, only very slight mould marking was apparent, and the shaping weighed 2 lb. A photograph of the complete lantern is shown in Fig. 13.

Experiments in high pressure moulding had shown that prismatic patterns could be reproduced with high accuracy on acrylic sheet, and temperature investigations indicated that their demoulding temperature was likely to be higher than that encountered in most sodium lanterns. Sample refractor plates have been produced, and prism accuracy of a high order achieved. A plate with enclosed prisms can be made by cementing a thin sheet over the prisms to a suitable edge pressed in the plate for this purpose. As these plates are easily cemented to another piece of the material, it seemed possible that a transparent prism "cover slip" could be made, which would be an integral part of the lantern, and eliminate the necessity for metal frames. This finally led to the design of an enclosed sodium lantern (Fig. 14). This unit consists primarily of an acrylic sheet dish and cover, carried from a simple casting. The dish is of the type described earlier, and not only totally encloses the lamp but also acts as a carrier for the refractor plates which are cemented to its inner surface in such a way that the prisms are enclosed. The cover for this unit is made from the reflecting opal 060. This fitting has advantages of lightness, complete enclosure of the lamp, high and consistent prism accuracy and general resistance to corrosion. The only metal parts exposed are the end support and the fastenings for the bottom dish. The use of the acrylic cover eliminates painting both at production and during service. Long-term exposure of this dense opal material indicates that in some situations there may be slight pigment migration on the exposed surface, but this would in no way affect the performance of the fitting. New materials being developed should overcome all such chalking.

From experience gained with these early designs, it is thought that acrylic materials may help the designer of street lighting equipment to solve some of the problems associated with this application and assist maintenance problems by reducing breakage and controlling corrosion.

(4.4.) Mine Lighting

Some years ago a suggestion was made that a plastic material might be used for the transparent part of flameproof mine-lighting fittings, but it was then thought that it would not be suitable due to surface softness and dust collection caused by induced static charges. The development of coal-face lighting and particularly the introduction of the fluorescent lamp[8] led to a request for transparent enclosures capable of resisting breakage by impact and satisfying the other requirements of B.S. 889. It seemed that acrylic mouldings could meet these requirements, and tests were commenced, particular attention being paid to abrasion and dust collection, as these were recognised limitations of the material. Shapings of normal types in which the material had not been thinned to less than ¼ in. passed B.S. 889 quite easily, so a trial in service conditions was made. Six bends in ⅜-in. sheet were placed at the coal face within about 3 ft. of the shot blast holes. At this distance flying stones from the shot explosion give a severe blow, often on a very small area. The bends survived for several weeks in these conditions, and, as a final test, were placed within 18 in. of a shot hole in which heavy charges were fired. Even in these conditions only two of the bends cracked, and it was concluded that the strength of the material was ample for the purpose.

In the next trial, six bulkhead fittings with dome covers were made by

Fig. 14. 140-watt sodium refractor street lighting lantern.

blowing from $\frac{3}{8}$-in. material, the stretch of the blowing reducing the thickness to $\frac{1}{4}$ in. at the top of the dome. These fittings were used with 60-watt lamps, and five survived a long test period without damage. The sixth dome was broken, but the cast-iron enclosing ring was also fractured. It was observed, however, that, when burned vertically, local demoulding due to high temperature had occurred.

The first units to be put into actual service were equipped with 15- and 20-watt fluorescent lamps, one fitting using a dish-type cover and the other an acrylic tube. These fittings are shown in Figs. 15 and 16. The dish of the first unit is moulded from $\frac{3}{8}$-in. acrylic sheet, and is fixed into the casting with "Kaffir" cement, the fixing bolts passing through the flange of the dish. Fittings of this type were installed at Chislet Colliery, and have given over six months' service. Examination after the first test period of three months showed that there had been no breakage, that surface abrasion was slight, and that surface pitting was negligible. It was noticed also that, despite the dusty atmosphere of the coal face area where the tests were made, there had been no obvious collection of dust due to static charge.

The tubes in the second type of unit are made either by fabrication from sheet or by centrifugal casting. In service the dish fitting is claimed to give slightly better distribution, due to greater end spill of light, while the tube units are said to be cheaper in construction and easier to render flameproof.

German practice during later years for both coal face and roadway lighting tended toward the use of opal enclosures for filament lamps as the glare from bare lamps or refractor units was considered objectionable. The introduction of high transmission opal acrylic sheet has enabled a $\frac{3}{8}$-in. thick material to be made, giving good diffusion, coupled with a transmission of the order of 60 per cent. It is thought that, as this material withstands the necessary impact tests, it may find use in filament lamp fittings. Care will be necessary in design, however, to prevent demoulding.

Experiments have also been made in the pressing of refractor dishes for tungsten mine-lighting units. These mouldings have been successful, but again care must be taken in their use, otherwise demoulding of the prisms occurs.

The use of acrylic sheet has been confined to fittings in Group 1 of B.S. 229, i.e., fittings for use in coal mines in an atmosphere where concentrations of methane are likely to occur. Other group classifications cover fittings for use where vapours of such liquids as acetone, benzol, and xylol are present. It has already been indicated that high concentrations of certain of these vapours may have the effect of crazing or swelling the surface of the material. Tests are

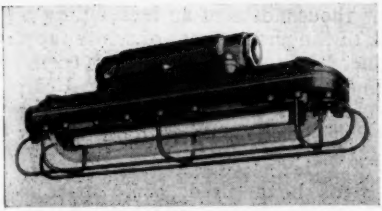


Fig. 15. Mine lighting fitting with moulded acrylic cover.

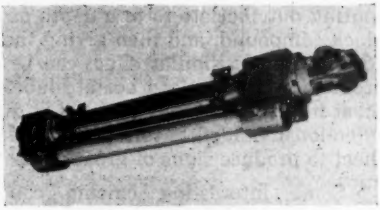


Fig. 16. Mine lighting fitting with cast acrylic tube enclosing fluorescent lamp.

being made in these conditions, but, until more information is available, it is recommended that acrylic materials should not be used in these locations.

(4.5.) Transport Lighting

Transport lighting demands a material able to withstand the vibration and weave associated with trains and road vehicles, the problem being accentuated by the introduction of fluorescent lighting. Acrylic sheet has been extensively used in American train lighting, and is now receiving attention from British designers. Several transport lighting installations have been completed, and various types of fittings used, the simplest and probably the most serviceable type being the tramcar fitting show in Fig. 17. Here simple fittings consisting of ribbed bends are used enclosing 18-in., 15-watt fluorescent lamps. These are housed in light sheet steel surrounds, and are easily removed for cleaning. Decorative units in patterned, sandblasted material have been used for railway carriage installations, and advantage has been taken of the flexibility of the sheet to construct fittings with no hinges or catches, the bends being sprung into position.

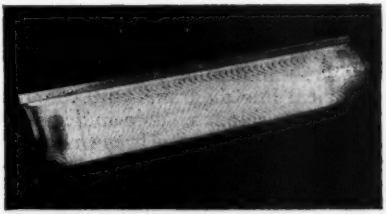


Fig. 17. Tramcar fitting for 15-watt fluorescent lamp using machine-fluted acrylic cover.

(4.6.) Sign Lighting

Increasing use is now being made of all types of acrylic sheet in the construction of attractive and efficient signs. Due to breakage of road bollard signs, both from accidental and malicious causes, tests have been made in the use of plastic materials. Owing to its good dimensional stability and high impact strength, acrylic sheet was found to be most serviceable, and is now coming into considerable use. Lettered signs of the "Keep Left" type are prepared by stencilling or silk screening the lettering on the back of the clear acrylic sheet, which is then coated with a white diffusing paint, often followed by a protective clear lacquer. To give reasonable safety from damage by flying stones, $\frac{3}{16}$-in. thick material should be used.

Box signs of the type usually made in opal glass with lettering of various types and colours have also suffered considerable damage by breakage. The method of lettering mentioned previously has enabled acrylic sheet to be used for these signs with good results. Another method of lettering is by

routing out the letters to a depth of a few thousandths of an inch, filling with black compound, and then giving the back of the sheet a coat of white lacquer. Alternatively a similar effect can be produced by the method employed in the production of cellulose acetate labels, namely by pressing a coloured carbon sheet into the material with a hot die bearing the required lettering or design. Injection moulded letters can be cemented or shock moulded to diffusing opal sheet to produce signs of great permanence.

Some interesting cinema canopy signs have used ¼-in. opal sheet backed by banks of tubular fluorescent lamps and bearing fabricated transparent coloured letters sliding in racks. These give good daylight and illuminated appearance, and the letters can be easily changed. The limitation on outside illuminated signs has proved a handicap in this application of acrylic materials, but many ingenious devices have been developed. Particularly interesting examples are those using total internal reflection to obtain the so-called "edge lighted" effects.(9) Light is introduced into the edges of the transparent acrylic sheet on the back of which a design is engraved or sandblasted. The light is transmitted along the sheet by total internal reflection, and escapes where the sheet surface is broken, causing the design to appear luminous. By placing a number of such illuminated sheets, each bearing part of a design, behind one another, an effective three-dimensional illusion can be obtained.

Some indicating signs have also made use of total internal reflection and electrical line diagrams with colour change have employed the same technique. Small size colour change indicating lamps have been made by mounting three coloured lamps at the broad edge of a polished acrylic wedge, whose thin end is flattened and rounded to ¼-in. circle. Each lamp is mounted in a separate white enamelled cell, and the light from the particular lamp indicating at any time is transmitted along the wedge and illuminates the end. By this system the space occupied by three-colour luminous indicators has been considerably reduced.

(4.7.) Maintenance

A paper on any new material in lighting would not be complete without some mention of the best methods of maintenance. The collection of dust due to static charge and the danger of surface abrasion by wind-borne dust or by cleaning, are two possible faults that can be avoided by reasonable care. The retention of static charge is due primarily to the high surface resistivity of acrylic sheet. To enable surface leakage to take place, the material is treated with a wetting agent in the form of a paste. This paste is applied thinly over the surface of the shaping, which is then lightly polished to remove any excess. The treatment lasts for a time depending on the vigour and frequency of polishing and on the atmospheric conditions in which the fitting operates. When fittings are used outdoors or in very dirty indoor locations, cleaning with soap and water has been found to be the best practice. Should serious abrasion occur, the high polish of the surface of the material can be restored by buffing with a soft mop or by polishing with an abrasive polish, followed by a non-abrasive finishing compound.

Provided that simple maintenance precautions, such as those outlined above, are observed, the service performance of fittings using acrylic sheet should be satisfactory, a conclusion confirmed by the considerable service data now becoming available.

(5) Conclusion

In common with every material used in the construction of lighting fittings, the acrylic plastics have properties which limit their possible application in this field of engineering practice. The boundaries defined by these limitations are, however, wide, and within them are many types of equipment where the material can efficiently serve the lighting industry.

Developments in high polymer chemistry and technology are so numerous that conjecture regarding new and improved materials would be unwise. None the less, it is reasonable to expect that, as experience in the application of the present acrylic plastics to lighting equipment broadens, new varieties of the material will be evolved.

Meanwhile, there are new applications to be investigated and new techniques to be devised, work which will require continued co-operation between members of both the plastics and lighting industries, if the full advantages of acrylic materials are to be realised.

The authors are indebted to colleagues and other members of the lighting industry for help in the preparation of this paper. They would also acknowledge the courtesy of the following companies for permission to use illustrations of lighting fittings:—British Thomson-Houston, Ltd.; Crompton-Parkinson, Ltd.; General Electric Co., Ltd.; Metropolitan-Vickers Electrical Co., Ltd.; Revo Electric Co., Ltd.; Thorn Electrical Industries, Ltd.

References

(1) Caress, Endeavour, 1944, vol. III, p. 156.
(2) British Patents 395,687, 405,699, 427,494, 427,810, 440,967, 444,257, 456,533.
(3) Starkie, Trans. I.E.S. (Lond.), 1944, vol. IX, p. 173.
(4) Winifred Lewis, "Thin Films and Surfaces." (English Universities Press, 1946).
(5) Tuckett, Trans. Faraday Soc., 1942, vol. 38, p. 310.
(6) Connell and Hogarth, Plastics, 1947, vol. XI, p. 414.
(7) Davies and Sinclair, Public Lighting, 1947, vol. 11, p. 151. Anon., Public Lighting, 1948, vol. 12, p. 100.
(8) McMillan, Light and Lighting, 1947, vol. XL, p. 156.
(9) Anon., Modern Plastics, 1947, vol. 25, p. 102.

APPENDIX

Resistance of Acrylic Sheet to Chemical Attack

1. Acrylic sheet is unattacked by the following chemicals at room temperature:—

(a) Saturated solution of sodium hypochlorite.
2 per cent. solution of chlorine in water.
10 per cent. solution of potassium dichromate.
Saturated solution of potassium chlorate.
Saturated solution of ammonium chloride.

(b) 10 per cent. nitric acid.
31 per cent. hydrochloric acid.
25 per cent. sulphuric acid.
50 per cent. acetic acid.
Saturated solution of citric acid.
50 per cent. phosphoric acid.
25 per cent. formic acid.
Saturated solution of oxalic acid.
Saturated solution of tartaric acid.

(c) Concentrated solutions of sodium hydroxide, potassium hydroxide, sodium carbonate, and 30 per cent. solution of ammonia.

(d) Many of the common gases, including ozone and sulphur dioxide.

(e) Aliphatic hydrocarbons, hydrogenated aromatic compounds, simple ethers, fats, and oils, e.g.,

Hexane
Cetane
Petroleum ether
Transformer oil

Petrol with low aromatic content.
Cyclohexane
Cyclopropane
Glycol
Glycerol

2. Acrylic sheet is attacked, but not readily dissolved, by the following chemicals at room temperature:—

Chromic acid containing 40 per cent. CrO_3
Methylated spirit
Methyl alcohol
Ethyl alcohol
Butyl alcohol
Iso-propyl alcohol
Allyl alcohol
Ethyl sulphate
Ethyl lactate
Ethylene dibromide
Carbon tetrachloride
Carbon disulphide
Tetrachlorethylene
n-butyl chloride
Butaldehyde
Butyric acid
Acetonitrile
Methylated ether
Diethyl ether
Petrol with high aromatic content
Cyclohexane
Solvent naphtha
Phenol
Cresol
Nitrobenzene
Monochlorbenzene
Dichlorbenzene
Benzoyl chloride
Aniline
Ethyl aniline
Metatoluidene
Benzaldehyde
Piperidene
Nicotine
Acetophenone
Glycerol monobenzyl ether.

3. Acrylic sheet is dissolved by the following chemicals at room temperatures:—

Liquid hydrocyanic acid
Chloroform
Acetone
Benzene
Toluene
Xylene
Ethylene dichloride
Trichlorethylene
Ethyl acetate
Butyl acetate
Amyl acetate
Glacial acetic acid

Discussion

MR. J. G. HOLMES said that this paper had given a most admirable description of the properties and the technique of working with acrylic plastics and had rightly and clearly stated some of the limitations which had to be borne in mind when using this relatively new material. There was always a temptation to be extravagant in claims and unduly optimistic in applications of a new material and the authors had avoided these tendencies almost to the extent of seeming

unduly conservative in their statements. It was clear that this new material, having different properties from those of glass, may be used in different ways and in different designs; each had its own part to play in the construction of lighting fittings and there should be no competition between glass and plastics when the properties of the two materials were more fully understood. For example, nobody had thought seriously of making lamp bulbs from an acrylic plastic and no one had suggested that articles such as spectacle frames ought to be made of glass rather than plastic. With this new material and its new properties, what a pity it was to copy the old designs which were developed particularly for glass and were limited by the properties of glass. The most notable point of the illustrations in the paper was that the acrylic mouldings looked just like glass ones and we ought, surely, to look forward to some novelty in designing for acrylic plastics to match the novelty in the properties and methods of fabrication.

In designing the components of lighting fittings to take best advantage of the properties of acrylic plastics it was desirable to be able to obtain the raw material in some other form than flat, parallel sided, polished sheet. Can we look forward to extrusion processes or to die-casting or injection moulding, or even to a cheaper form of direct casting of these acrylic materials so that there can be more scope in design of fittings as, indeed, we already had in glass fittings? The data in the paper related to polymethyl methacrylate but the authors referred to other acrylic polymers and there may be something further up the organic scale in the ethyl or butyl series which would give a material with less restricted properties or perhaps with some more desirable properties. Can we look forward to some harder acrylate or to one which will stand a higher temperature? We appreciated, of course, that polymethyl methacrylate was one of the best transparent plastics now available and, indeed, it was a very good one and very suitable for many applications in lighting, but its limitations were such that those of us who are used to glass are looking forward to something better.

Perhaps the most serious limitation was that of temperature. It was stated in the paper that de-moulding should not occur if the external surface temperature is 70 deg. C. and a simple calculation showed that for ¼-in. material this meant an internal surface temperature of 90-95 deg. C. under normal conditions. These temperatures seemed higher than had been quoted in the early publications on this material and experience showed that, whilst such temperatures may be safe for flat material or for shallow mouldings for relatively short periods numbered in days rather than weeks, the maximum safe external temperature for fairly thick mouldings in continuous use over periods of months was 60-65 deg. C. De-moulding seemed to be cumulative, and may proceed very slowly under intermittent use of a fitting, and the fullest possible data on the dimensional stability of mouldings should be made available as soon as the necessary time had elapsed for the experiments to be completed.

Fig. 3 in the paper showed that acrylic sheet was strongly absorbing to infra-red radiation even in ⅛-in. thickness and, therefore, that the sheet got relatively hot if placed near an infra-red source such as a filament lamp. The

following table showed the calculated total heat transmission factor of the plastic for radiation from a gas-filled lamp:

Calculated Data for Clear Acrylic Resin and Glass

Thickness of clear material	Total Heat Transn. Factor (2848 deg. K.)		Average Inside Temperature of 8-inch sphere of material with 100-w. lamp	
	Acrylic Resin as Fig. 3. per cent.	Pressed Glass. per cent.	Acrylic	Glass
Zero	92	92	20 deg. C.	20 deg. C.
1/16-inch	60	83	53 deg. C.	31 deg. C.
1/8-inch	52	77	64 deg. C.	36 deg. C.
1/4-inch	44	70	80 deg. C.	42 deg. C.

It was likely from the fundamental structure of acrylic plastics that the infra-red absorption was greater than shown in Fig. 3 if the temperatures were above normal and it would be interesting to have information on this point and also on the effect of adding colouring agents and opalescent materials. These figures would be very useful because, in designing a fitting for use with filament lamps or, indeed, with any lamp if the dimensions are to be kept small, it was very desirable to be able to calculate the operating temperature of the acrylic plastic.

There was another effect of temperature beside that of de-moulding on which little emphasis had been placed in the paper. In Fig. 5 it was shown that the mechanical properties were affected very considerably and, although the impact strength was reasonably constant from −40 deg. C. to 20 deg. C. and rose somewhat above 20 deg. C., the tensile strength fell continuously as the temperature was raised. At room temperatures the tensile strength was about 10,000-lb./in.², which was substantially the same as the average tensile strength of sheet glass. The strength tests in British Standard BS.889 for flame-proof fittings were designed for testing glass to ensure that it would withstand the temperatures and pressures likely to occur in service but it did not follow that the same tests were suitable for this quite different material to give the same degree of safety. The strength of glass did not change appreciably with temperature and, therefore, the impact tests, the hydraulic pressure tests and the explosion tests could be made at room temperature even though, in service, the glass ran at perhaps 75 deg. or 80 deg. C., but the acrylic material had very greatly reduced tensile strength at higher temperatures. For example, at 75 deg. C. its tensile strength was only 1/5th of that at normal temperatures and a moulding which would just withstand a pressure of 150-lb./in.² at room temperatures would only withstand 30-lb./in.² at 75 deg. C. It required to be shown that a hot acrylic moulding would withstand the impact and pressure requirements in BS.889 and it would be of considerable interest if data could be made available.

The acrylic opals were, perhaps, a bigger advance in properties of materials for lighting purposes than the clear acrylic plastics. The authors indicated that there was a "spectrum" of opals from lightly scattering opals to opaque diffusers, but the word spectrum implied a continuous series of gradually changing properties whereas, in this paper, the opals were of four types which

appeared to be quite distinct in respect of their fundamental structure, and, therefore, in respect of their properties also. The value of these new opal materials lay not only in the ease of fabrication but also in their high optical efficiency because, with chemically pure constituents, the absorption of light can be kept low. There were two points in which the data given in the paper seemed to call for some modification. It was stated that the "high surface gloss on the 060 material enabled it to be treated in the same way as vitreous enamel when designing contours in relation to the specular component of the reflected flux," but this surely could not be true because these materials had a refractive index of about 1.49 whereas a white vitreous enamel may have a refractive index as high as 1.65 and the corresponding reflection factors for normal incidence were 3.9 per cent. and 6.1 per cent. At oblique incidence the ratio of the reflection factors was nearer unity but a low refractive index always gave a relatively low reflection factor. If, in addition, the crystalline pigment in the dense opal was liable to break down slightly under difficult weathering conditions this chalking would, of course, impair the surface polish and reduce the specular reflection. The second point was that the diffusion coefficient stated in Table I was in terms of the brightness ratio B_{45}/B_0, but the standard basis of description of diffusing power agreed internationally in 1939 was the ratio $(B_{20}+B_{70})/2\times B_5$, and it would be valuable to have the corresponding figures for these materials.

There had been many papers on plastics in lighting but the present paper was more frank and more comprehensive than any which had been widely published and was likely to be used as a work of reference throughout the industry.

Mr. T. S. JONES said that such a comprehensive report as that presented by the authors had the effect both of inspiring one's thoughts and at the same time of answering in advance certain general criticisms which applied to plastics as they were known and as they had been used or misused.

There were several references to the properties of the material in relation to filament lamp fittings, but it was his view that the use of acrylics in this field was likely to be confined more or less to the domestic or speciality lines where colour, eye appeal or novelty were of greater importance than the control of light, efficiency, etc.

One exception to this view may be found where high-shock or impact resistance was required in fittings for special purposes. However, the temperature limitations of acrylic material placed a boundary upon such uses.

Generally speaking, the material appeared to show its advantages to the maximum when applied to fluorescent lighting fittings designs where the adaptability of sheet in its various forms of opal and machined effects could be used to give expression to the designer's views.

As a substitute for glass or for metal acrylics had limitations, but also they provided considerable scope, and it could not be too greatly stressed that fittings should be designed to suit the material without too many traditional ideas controlling its use.

As an example one may take the case of the industrial fluorescent unit where the optical properties of opal glass are admirable for many applications, as had been appreciated by the extensive use in the past of industrial diffuser units to provide better quality lighting than that obtainable with industrial dispersive reflectors.

The optical properties of opal glass were admirable for such uses, but no one would consider installing glass units of this design some 5-ft. odd in length,

as their manufacture and use would be quite impracticable, but such units made of opal acrylic were very practicable and were widely used in better quality industrial work.

Metal fittings, of course, were useful in this field and have lower initial cost, but the rate of deterioration of stoved enamel metal in comparison with opal plastic was high, and even the more permanent vitreous enamel suffered by having greater absorption and very much greater weight. The appearance of an installation of opal acrylic units where all brightnesses within the visible field were pleasantly graded, appealed to all discerning lighting folk.

Apart from production areas of many industries, the value of such semi-direct, properly brightness-graded installations in offices was considerable, and the fact that well-arranged schemes of this kind were widely accepted in drawing offices forms the highest of recommendations, as those who have had to satisfy draughtsmen will testify.

As the authors had briefly mentioned " anti-dust " or anti-static preparations in their reference to maintenance, it may be of interest to the assembly to hear that in field experience such application was necessary at intervals of only 3-6 months in order to meet the usual maintenance factors in dry interiors. In wet interiors the application of such preparation was obviously unnecessary.

One point on which more information from the authors would be valuable referred to total reflection factors at angles from 90 deg. incidence to grazing angle, as this would prove useful in calculating the total output of any projected design. The figures might well prove significant, as there seemed little else to explain the very high efficiency of opalised acrylic material when used for normal semi-direct units. Field experience indicated that the reflected component of light output is at least 10 per cent. greater than that of the highest quality enamels.

The decorative value of machined patterns could be very high when used intelligently by the artist to accentuate or moderate a line, but it was advisable where machined surfaces had been produced to have the material surface treated to smooth out minute tool marks which otherwise acted as dust-collecting surfaces, and such surface treatments were relatively expensive.

Some further information from the authors regarding such treatment would be welcome, as the simple application of a solvent to smooth out such marks often resulted in chalkiness appearing after a period of use.

It was appreciated that the materials were also available in a considerable range of transparent and translucent colours which, in themselves, were very attractive, but which had properties of selective transmission rendering them difficult to use, particularly with fluorescent sources. Perhaps in due course some figures or graphs of the transmission over the visible range could be prepared for such materials in order that a rough forecast of the result might be made by the designer.

Before closing his remarks, he asked whether there was any possibility of extruded sections being available, because it occurred to him that the permanent colour and excellent finish of the material, coupled with its ease of handling, might render it most useful for applied decorative effects and, of course, additional to such extrudings, the availability of the material in liquid form for low temperature casting of decorative embellishments would widen the range of application very considerably.

Mr. J. C. Lowson, referring to the difficulty due to static charge, asked if this also applied to the opal material and could any improvement in that connection be anticipated in the near future. The opal material was used

mainly in interior fittings, and the dust problem was greatest in those circumstances.

He also inquired whether thought was being given to the use of infra-red heat in the bending of these plastics. He knew it had been used in the case of the earlier plastics for covers for street lamps, and considerably improved results had been obtained because it was possible to bend the sheet over at one particular point, leaving the flat surface unheated, which was a saving of power and time.

Mr. W. D. SINCLAIR asked for information as to the temperature change reached by this material under the influence of solar heat. He had in mind, he said, the use of the corrugated material for roofing purposes and the fact that this material might be exported to the tropics. Therefore, it would be interesting to know if in India or the middle of Africa the heat was likely to be such as to endanger the stability of the material.

Mr. P. HARTILL said he had heard that acrylic plastic was attacked by acetone vapours. How far was that a danger and were any steps being taken to meet it?

Mr. G. TOMLINSON asked what was the heat loss, from the building point of view, compared with glass.

Mr. L. J. ROBERTSON (Singapore) asked for information as to the effect of ultra-violet rays an acrylic plastics, particularly when used for street lighting lanterns and also for roofing purposes in the form of corrugated sheet. So far, he said, he had only been able to find there was slight loss of transmission after a fairly long exposure, but was there any change in colour?

Mr. F. L. CATOR asked if the tendency to collect dust through static charge was reduced with age. How long had plastics to be used before the tendency to static charge was very greatly reduced?

Mr. F. M. WOOD asked what was the difference, if any, as regards static charge in the case of plastics used outdoors and indoors.

MR. C. J. ALLDERIDGE remarked that it had been said that when plastics were moulded, all the strains were locked up. Where it was necessary to drill, would that drilling cause a tendency to fracture or should the drilling be carried out as far as possible in the portions not under stress?

MR. S. S. BEGGS asked what prospects there were of rolling this material.

MR. C. J. KING, referring to the use of louvres, asked if any attempt had been made to produce a type of louvre with this material for directional transmission.

MR. J. S. MCCULLOCH, referring to the use of this material in domestic fittings, said that 70 deg. C. was 150 deg. F. That was certainly very hot water to put one's hands in but it was possible that fittings might be dropped into water of that temperature when, for example, spring cleaning was in progress.

What was the danger in that case? Also, with regard to abrasion, in ordinary cleaning there might be effects which would influence the transmission from both clear and opal material if some forms of abrasive powders were inadvertently used or the duster had abrasive material adhering to it.

MR. C. H. LOGAN (Communicated) said he would like the authors to give him some indication, if at all possible, in connection with any progress made relative to case hardening of acrylic plastics. He had in mind several applications, especially in the field of street lighting, where visors made from plastics were subjected to a form of sand-blasting due to atmospheric conditions.

MR. HOWARD LONG (Communicated) said that the authors had presented this matter in a very fair and balanced manner. Here we had a new tool for the use of lighting engineers, and when used under appropriate circumstances it could be very useful. Much wider use of this tool would be possible when more experience had been gained and, as a result, the product had been further developed. The disadvantages which had been found were the static attraction of dirt, the warping or deforming, and the temperature limitation.

Much harm had been done to the good name of such plastics by their inappropriate use. It must be appreciated that lighting fittings were not generally maintained in a clean condition, and fluorescent troughs moulded from this material in its translucent form were to be seen very widely in a dirty state.

Replying to the discussion, THE AUTHORS said they would like to reemphasise that the development of the material was still in an early stage, and that there were gaps in our knowledge of its properties.

Replying to Mr. J. G. Holmes, they agreed that glass and acrylic plastics were complementary materials, and, as development increased, the demarcation line between the materials would become increasingly definite. It was acknowledged that the illustrations in the paper looked like glass, but consideration would show that some of these acrylic shapings could not have been satisfactorily made in glass. New techniques of production and possibilities of new materials were being investigated, but the acrylic material described in this paper seemed to have the best balance of properties for lighting applications.

The figures Mr. Holmes gave for the temperature gradient of acrylics and glass would be accepted, but practical tests indicated that mouldings were usually safe against de-moulding, if the surface temperature did not exceed 70 deg. C. It was emphasised, however, that trouble usually occurred due to local de-moulding caused by convection streams. De-moulding was cumulative, but, if the limits laid down were observed, total dimensional changes should be negligible over periods of many years.

In reply to Mr. Holmes' comments on the change in mechanical properties with temperature, with particular reference to BSS 889, if a moulding was so designed that at room temperature (20 deg. C) it passed BSS 889 impact test, it should, if worked within the temperature limit of the specification, successfully withstand the manometric pressure test required by the specification. Although tensile and compression strengths decrease with increase in temperature, impact strength increases considerably.

With regard to reflector contours in 060 dense opal acrylic sheet as compared with vitreous enamel, the authors felt that Mr. Holmes rather exaggerated

the importance of the variation of refractive index. In practice vitreous enamel reflectors are designed "off the surface."

They thanked Mr. Holmes for drawing attention to the expression for diffusion

$$D = \frac{B_{20} + B_{70}}{2B_5}$$

The figures for 030 and 040 opal acrylic sheet in $\frac{1}{8}$-in. thickness were as follows:—

030 opal, D = 0.35
040 opal, D = 0.87

Mr. T. S. Jones' comments were of great interest because of Mr. Jones' wide experience of the use of these materials in service. His indication that acrylic reflectors had an initial efficiency some 10 per cent. greater than that of other materials was confirmed by other manufacturers.

Regarding solvent finishing, there were a number of methods, both of polishing and obscuring by solvent application, or immersion, but the success of these treatments depended on avoiding surface crazing.

There were no extruded sections in acrylic plastics available commercially in this country at present, and casting was not an economical method of producing small decorative parts. These could often be made by injection moulding, using an acrylic moulding powder.

Mr. Jones' remarks on the successful use of anti-static paste were of particular interest, and answered one of Mr. Howard Long's criticisms.

Replying to Mr. J. C. Lowson, they said that the opals retained static charge in the same way as the clear materials. It was possible to make a sheet which did not retain static charge to the same extent, but to do this other more valuable properties had to be sacrificed.

Infra-red heating was often used for acrylic sheet, and considerable data was available on this subject. Focused or vignetted infra-red was extensively used where localised softening was required.

In answer to Mr. W. D. Sinclair's question on the effect of tropical sun, experience with aircraft components suggested that the clear material should be satisfactory. Tests were, however, in progress, and the results would be made available as soon as possible.

In reply to Mr. P. Hartill, "Perspex" may be swollen or crazed in very high concentrations of acetone vapour, but the concentrations and conditions to cause such attack were not likely to occur in industrial service.

Replying to Mr. G. Tomlinson, they said that experience showed that heat loss in buildings using "Perspex" glazing was lower than in those using glass.

In reply to Mr. L. J. Robertson, there was no loss in transmission in the visual spectrum, and no discolouration of unplasticised clear acrylic sheet after prolonged exposure to ultra-violet radiation of the type occurring in solar radiation. There was, however, a slight variation in ultra-violet transmission after such exposure.

Mr. F. L. Cator's suggestion that acrylic sheet loses its ability to retain static charge with age had been made by a number of people, but there was no experimental evidence to support the idea.

Replying to Mr. F. M. Woods, where the material was used in the open air, as in street lighting lanterns, field experience showed that once an original charge is dissipated it rarely builds up again.

In reply to Mr. C. J. Allderidge, failure due to cracking at holes drilled in

"Perspex" was more often due to strain induced by drilling rather than by the release of strain already present. It was wise not to drill holes too near the edge of the material, and either to polish the insides of the holes or relieve strain by warming the area round them with a flame. The locking of strain in the material sometimes caused a small reduction in impact strength, but this was often coupled with an increase in tensile strength.

Replying to Mr. S. S. Beggs, the authors stated that the impression of patterns on clear material by rolling would not be satisfactory, as the patterns would disappear during subsequent moulding. To obtain permanent patterns it would be necessary to cast the syrup in suitably figured moulds, and this might be possible in the future.

Replying to Mr. C. J. King, they said that development work was in hand on translucent louvres. A marked reduction in louvre surface brightness was possible, together with an increase in efficiency due to the low absorption factors of the acrylic opals.

Replying to Mr. J. S. McCulloch, they knew of no instances of de-moulding during "washing up," although many thousands of acrylic kitchen utensils were in use.

Significant degradation of the optical performance of lighting fittings was rare; field experience had shown this to be very much less than was anticipated from empirical tests. If serious abrasion did occur it was quite easy to restore the surface finish by buffing or by the use of polishes.

Replying to Mr. C. H. Logan, they said that there was, to their knowledge, no satisfactory commercial method of hardening the surface of sheet acrylic materials. Several methods had been tried, but so far without real success.

In reply to Mr. Howard Long, a record of field experience was gradually being built up, which will give valuable experience in defining what are "advantageous" uses. Trouble due to warping was usually traced to a moulding fault, generally the removal of the material from the mould before it was properly cool. It had been found that, when properly moulded, acrylic materials were dimensionally stable. The broad term "plastics" included materials which were by no means stable, and often gave the impression that all plastics had this fault.

When any new material was developed it was almost certain that someone would misuse it, and with the material under discussion this must be expected. The authors had tried to give in this paper some guidance both as to the advantages and limitations of acrylic plastics for this large and important application.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—"Trans. Illum. Eng. Soc. (London)."

Obituary

SIR CLIFFORD PATERSON

We deeply regret to announce the death on Monday, July 26, 1948, of Sir Clifford Paterson, O.B.E., D.Sc., F.R.S. (Fellow).

Few other men were as well known and respected in the lighting world as Sir Clifford. He made substantial personal contributions to photometry in the early part of his career and, in spite of increasing responsibilities and an ever-widening circle of activities, he never lost his interest in lighting. He served on many committees, frequently as chairman, in which position he was recognised as having few superiors. He served as president of many scientific and technical bodies, including the Illuminating Engineering Society, always with distinction. He was honoured in many ways by many people, the crowning glories being perhaps his election to Fellowship of the Royal Society in 1942 and his Knighthood of 1946.

Sir Clifford never regarded these distinctions as personal to himself; they always represented the achievement of the team which he led at the research laboratories of the General Electric Co., Ltd., at Wembley. The laboratories were his creation and his working life. They represented his belief in the union of science to industry: a belief which he avowed in a practical way when, in 1919, he left the National Physical Laboratory to join the G.E.C. In those days he was one of a very few who foresaw the value of such a union, although now it is accepted as obvious.

Clifford Copland Paterson was born in 1879 and was educated at Mill Hill School. He had some five years of practical training in London, Glasgow and at the Oerlikon Works in Switzerland before studying electrical engineering at Finsbury Technical College and Faraday House. He went, in 1903, to the National Physical Laboratory, where he stayed until 1919. During this time he had charge, under Sir Richard Glazebrook, of the Electro-technical and Photometric departments and made many contributions to precision measurements of electrical power and the standard of light. With Dudding particularly he made determinations of the effects of humidity and pressure on the candle-power of the pentane lamp; later they were concerned in standardising tungsten filament lamps against carbon standards bridging the colour difference by the "cascade" method.

During the 1914-18 war Sir Clifford was concerned with devices for military purposes; the best known being, probably, an electric height finder for automatic indication of aircraft height. This was developed with Walsh, who is himself one of the most illustrious members of the lighting community. For his war work Sir Clifford was awarded the Order of the British Empire.

In 1919 the main task began. Sir Clifford, while at the N.P.L., must have been forming his ideas on industrial research, and the invitation to organise a research group for the G.E.C. gave him an opportunity to put those ideas into effect. The staff, in those early days, was only 29: to-day it is over 1,200. The original purpose of the group was research on light sources: now it includes radio, radar, television, heavy engineering, lighting and many other subjects. In spite of this great expansion, all of the important basic concepts of Sir Clifford remain. The laboratories serve the company but with a great freedom of action. The members of the staff—Sir Clifford had a great flair for picking men—are encouraged to understand production and commercial problems so that they do not work, as it were, in a vacuum; they are also encouraged to work on subjects of less obvious industrial value, and to publish

the results of these researches. A successful endeavour was made to prevent research workers from being over-burdened with administration.

Some of the contributions of this team have been outstanding. On light sources their work on the mercury vapour discharge is best known. The high-pressure discharge investigations led to the familiar 400w. lamps first used in June, 1932, for public lighting. The latest developments along these lines have resulted in quartz "compact-source" lamps of high efficiency, high brightness and much improved colour. The low-pressure discharge was utilised in 1933 to provide fluorescent lighting of interiors using high voltage tubes, and from these followed the mains voltage lamps which represent perhaps the greatest advance in light sources since the introduction of tungsten filament lamps. In parallel with research on lamps has gone the study of photometry.

It is natural that the director of an important laboratory should, from time to time, be asked to fill important offices and receive honours: but Sir Clifford was sought after in a most remarkable way. The reason was, in part at least, that he never accepted any reward without accepting its obligation. For example, he had been Faraday Lecturer of the Institution of Electrical Engineers, Guthrie Lecturer of the Physical Society and Huxley Lecturer of Birmingham University. Those who heard any of these will know that they were not the formal thanks from a man accepting an honour, but the sincere effort to interest an audience in the lecturer's own interests; no pains were spared in their preparation and the results were always brilliant.

Sir Clifford was president of many learned societies, including the Illuminating Engineering Society and Institution of Electrical Engineers. He was president of the International Commission on Illumination (1928-31) and honorary secretary for many years. He was always a great believer in the work of the British Standards Institution, of which he was chairman of the General Council, and he was a member of the Advisory Council of the Department of Scientific and Industrial Research. He was chairman of the Lighting of Buildings Committee appointed by the D.S.I.R. in 1942 to study lighting in post-war buildings. Throughout the war Sir Clifford was chairman of the Government Inter-Services Valve Technical Committee.

His degree of D.Sc. (honoris causa) was awarded in 1937 by Birmingham University, his Fellowship of the Royal Society in 1942. He received the I.E.E. Faraday Medal in 1945, a Knighthood in 1946, and the James Alfred Ewing Medal (Royal Society and Inst. of Civil Engineers) in 1947. In 1948 the American Illuminating Engineering Society awarded their Gold Medal, for the first time to a foreigner, to Sir Clifford Paterson. It seemed almost that a man could not bear himself naturally under such a burden of distinctions. If it had any effect on Sir Clifford it was only, in the opinion of those near him, to make him even more unassuming and even more willing to give credit to his Wembley team than before. Amidst it all he still retained many other interests in life; in his garden, of which he was justifiably proud; in the Worshipful Company of Tallow Chandlers, with which he had a lifetime's association and of which he was Master from 1939-41.

Perhaps above all things he never wavered in his deeply rooted religious beliefs. A lifetime devoted to science had not shaken those beliefs as it has done for others, and in all that Sir Clifford did his Christian faith was evident.

In this particularly, but also in all his other activities, Sir Clifford received great help and comfort from Lady Paterson. She is well known to many members of the I.E.S. and well loved by all who know her. We offer her our most sincere sympathy.

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

SUSTAINING MEMBERS:—

South-Eastern Electricity Board.....*Representative*: C. F. Wells.
5-6, Lancaster Place, Strand, W.C.2.

John Walsh Walsh, Ltd.....*Representative*: A. Kray.
Soho and Vesta Glassworks, Lodge Road, Birmingham.

CORPORATE MEMBERS:—

Collot, M. .....54, Rue Taitbout, Paris, FRANCE.
Cotton, S. G. .....30, Park Cross Street, LEEDS, 1.
Crawford, J. .....Dublin Road, BELFAST.
Hawker, R. C. G. .....25, Howitt Close, Howitt Road, LONDON, N.W.3.
Kirkham, K. W. .....Windy Ridge, 96, Banks Lane, Riddlesden, Keighley, YORKS
MacCarthy, B. J. .....British Thomson-Houston Co., Ltd., 26-27, St. Mary Street, CARDIFF.
McCauley, J. L.....19, Davis Street, Longsight, MANCHESTER.
O'Neill, R. H. .....East Hull Gas Company, St. Mark Street, HULL.
Pidgeon, J. .....“Annandale,” Ankle Hill, Melton Mowbray, LEICS.
Smith, T. D. .....9, Rosslyn Avenue, Low Fell, GATESHEAD, 9.
Taylor, I. .....6, Brenka Avenue, Aintree, LIVERPOOL, 9.
Whitfield, J. N. .....Willow Green, Butley Lanes, Prestbury, CHESHIRE.

COUNTRY MEMBER:—

Mattalon, R. W. .....47, Rue des Pharaohs, Alexandria, EGYPT.

SYMPOSIUM ON SEARCHLIGHTS

The five papers on searchlights and associated subjects which were presented at the sessional meeting of the Society on April 15, 1947, have now been published in one volume. The papers deal with the function and design of army searchlights, high-power searchlights, photometry of searchlights, and visibility problems in naval and anti-aircraft work. The book also includes the discussion which followed the presentation of these papers and a further contribution dealing with aircraft searchlights in anti-submarine work.

Copies of the book (price 17s. 6d.; by post, 18s. 6d.) may be obtained from the Secretary, The Illuminating Engineering Society, 32, Victoria Street, London, S.W.1.

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